Advancing precipitation retrievals from cross-track sensors

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Introduction

The Global Precipitation Measurement mission provides an international constellation of both conically-scanning 'imaging' instruments and cross-track 'sounding' instruments. Techniques to generate estimates from conically-scanning sensors have a long heritage, while those from cross-track sensors have a relatively short history despite forming the majority of sensors within the GPM constellation: the inclusion of their estimates is crucial to meet the necessary temporal sampling required to capture the variability of precipitation. Improving and advancing precipitation retrievals from these cross-track sensor is therefore vital: two schemes are considered here.

The Goddard Profiling Scheme (GPROF) *(Figure 1 Left)*

The GPROF retrieval scheme provides estimates for all the constellation sensors except for SAPHIR. The GPROF *a priori* database is initially generated from about 400M GMI and DPR matchups. Work is done to minimise differences between the observed Tbs and the DPR rainrates through the optimisation of hydrometeor profiles. Information on the Tbs, DPR rainrate and hydrometeor profiles are then used to generate database for the other sensors in the GPM constellation, taking into account the differences in frequency, resolution and incidence angle.

The Precipitation Retrieval and Profiling Scheme (PRPS) *(Figure 1 right)*

The PRPS exploits the co-located observations from the DPR and each of the constellation passive microwave sensors to build observational databases for each sensor. The number of orbital intersects and number of co-located fovs for each sensor is shown in Table 1. The PRPS inherently incorporates the differences in resolution and incidence angle into its' database, and since it is sensor-specific, the sensor frequencies. The variable Earth Incidence Angle (inherent in all cross-track sensor observations) is accounted for through comparing alike observation-database scan positions (Figure 2).

But, how much information is contained cross-track sounding channels? Typically sounders contain less information than the imagers do in their observations.

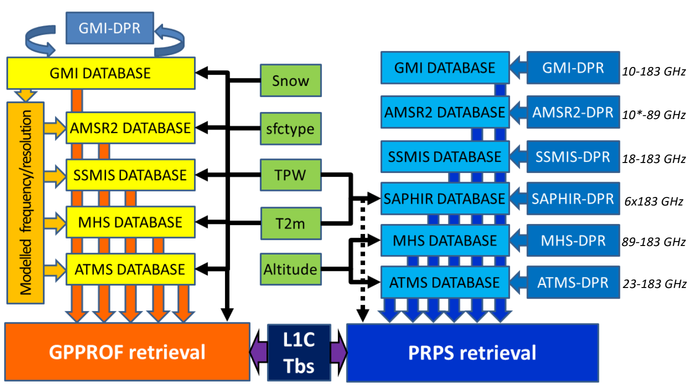


Figure 1: Schematic of the GPROF retrieval scheme (left) compared with that of the PRPS (right).

Figure 3 (right): Simulations of retrievals using different channel combinations: Left column = GPROF retrievals , **right column** = PRPS retrievals; **Top to bottom**, all channels, low frequency (10-89) only, ATMS-like channels (23, 89, 166, 183) only; MHS-like channels (89, 166, 183) and SAPHIR-like channels (183 only). GPROF retrievals use a c.400M GMI:DPR entry database constrained by TPW/T2m/surface, the PRPS uses a c.14M GMI:DPR entry database, unconstrained.

Table1: number of cases and field-of-views of DPR:sensor matchups generated for the PRPS-database, together with the retrieval resolution and constraints.

Sensor	Cases	FOVs	Resolution	Constraints
SAPHIR	3,237	14,115,806	5x5 km	TPW/T2m
MHS	27481	39886841	15x15 km	Altitude
ATMS	7,806	3,646,164	15x15 km	None
SSMIS	14,386	31,718,079	15x15 km	None
AMSR2	3,812	14,804,012	15x15 km	None
GMI	3,812	14,804,012	15x15 km	None

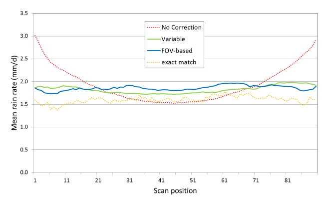
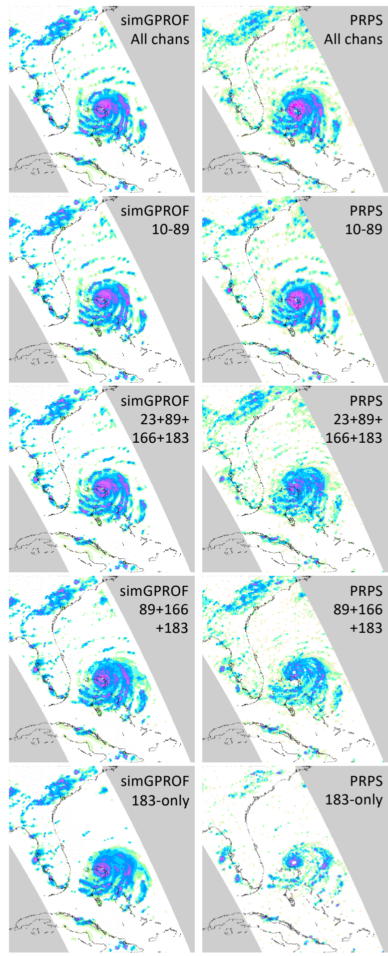


Figure 2: Scan position matching: accounting for scan positions within the PRPS retrieval scheme by selecting alike scan position database entries any bias can be virtually eliminated.



simGPROF simulations

A simplified GPROF retrieval (simGPROF) is performed using GMI Tbs with an associated GMI-DPR database created using the 2Bcombined retrievals from the inner, dual-frequency swath. c.400M DPR:GMI matchups are clustered using a kmeans analysis to group self-similar entries. A simple Bayesian methodology, constrained by 2m temperature, TPW and surface type is used for the retrieval. Here the relative channel weightings of the retrieval are manipulated over the ocean to include/exclude specific channels. The top left panel uses all the 13 GMI chanels, i.e. the 'best possible' retrieval. Below this is a retrieval based upon the lower-frequency channels (10-89 GHz), then the ATMS-like frequencies, MHS-like frequencies, while the bottom shows the retrieval based upon SAPHIR-like frequencies (albeit with only 2 out of the 6 channels).

PRPS retrievals

The PRPS retrievals are based upon a database of GMI:DPR matchups (c.14M): all database entries are searched to find the six closest entries to the observed Tbs. For this comparison the retrievals are unconstrained – i.e. no ancillary data was used. The PRPS simulated retrievals for the same channel combinations are shown to the right of those of the simGPROF retrievals.

Comparison of the simGPROF and PRPS clearly shows that as the number of channels/frequencies decreases the information contained within the retrieval decreases. Critically, it can be seen that the ATMS-like, MHS-like and SAPHIR-like retrievals show some significant deviations from the simGPROF retrievals: the 2x183 channel PRPS demonstrates that constraining the retrievals by T2m/TPW is critical: if all channels are available the differences between the constrained GPROF and unconstrained PRPS is relatively small.

The PRPS scheme is utilised by NASA's PPS as the operational retrieval scheme for SAPHIR. To circumvent the issues highlighted here the PRPS-SAPHIR retrievals use the same T2m/TPW constraints as used by GPROF. By doing so this makes the scheme more aligned with the GPROF retrievals.

Fundamentally, the breadth of the channel frequencies is crucial in providing an accurate retrieval in the absence of ancillary data sets.

Modelling of Tb:RR relationships

To better understand the extent to which sounding instruments can be used in the retrieval of precipitation improvements in the modelling of the Tb:RR relationship is crucial.

Microwave Tbs are calculated from randomly sampled 2D cloud-resolving model (CRM) simulations of the NASA Multi-Modeling Framework (MMF). From each 2D CRM column, Tbs are calculated for 110 sensor viewing angles that are projected to local elevation angles for radiative transfer calculation. The derived CRM-scale Tbs and surface rain rates (RRs) are averaged by Gaussian weighting function of half power beam width to represent sensor-scaled Tbs and RRs. These calculations assume Mie (sphere) scattering with Maxwell-Garnet mixture assumptions for the dielectric constant of each hydrometeor species, while the surface emissivity is estimated from the observed climatology from the TESLSEM. All Tb calculations assume plane-parallel assumption for this figure. Tbs are averaged for given RRs for each sensor channels.

The mean Tb per rain rate for the SAPHIR and MHS frequencies/channels is shown in Figure 5 and 6 below, together with mean Tbs derived from SAPHIR/MHS:DPR comparisons. As a first-run the agreement between the model and observations is very encouraging. Differences between the two are generally less than a few K at the lighter rain rates: at higher rain rates the paucity of samples leads to greater variations in the Tb:RR relationships. Nevertheless, Kidd et al. (2016) showed that model-derived data could be usefully employed to retrieve precipitation from the MHS sensor.

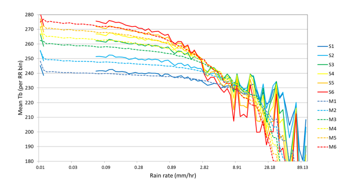


Figure 5: Mean brightness temperature (Tb) per rain rate for the six 183 GHz channels of the SAPHIR instrument derived from matchups between SAPHIR and the GPM-DPR (solid lines) and as derived from the MMF model (dashed line).

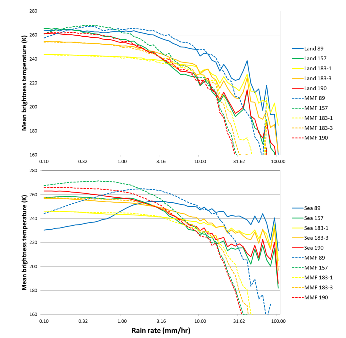


Figure 6: Mean brightness temperature (Tb) per rain rate for the MHS channels for MHS:DPR match ups (solid line) and MMF-modelled Tbs, for land and ocean.

Acknowledgments:

This research is funded through the NASA PMM program, award 80NSSC19K0825. The authors are grateful to the many fellow researchers that have contributed to this work, and of the necessary support staff at NASA and University of Maryland/ESSIC.

Reference:

Kidd, C. and Matsui, T., Chern, J., Mohr, K., Kummerow, C. and Randel, D. 2016: Global Precipitation Estimates from cross-track passive microwave observations using a physically based retrieval scheme. *Journal of Hydrometeorology*. 17 383-400.